

Description

Laminated Windings for Matrix Transformers and Terminations Therefor

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This is a continuation in part of a provisional application of the same name, serial number 60/460,332 filed 3 April, 2003. Priority to that date is claimed.

BACKGROUND OF INVENTION

[0002] This invention relates to matrix transformers, and in particular to matrix transformers having multiple turn primaries, either single coil windings as for a full bridge, half bridge or forward converter or multiple coil windings as for push-pull windings, split windings or a forward converter having a reset winding.

[0003] Figure 1 shows a prior art magnetic core 1 as may be used to make a matrix transformer. Figure 2 shows a phantom view 4 of the magnetic core 1 of figure 1 further compris-

ing first and second secondary windings 2 and 3. Figure 3 shows a prior art "element" 5 of a matrix transformer comprising a pair of magnetic cores 1, 1 which are the magnetic core 1 of figure 1 each further comprising first and second secondary windings 2 and 3. The secondary windings 2 and 3 may be connected in various arrangements as required by a particular application.

- [0004] Figure 4 shows a prior art matrix transformer 10 comprising five magnetic elements 5-5 which are the magnetic element 5 of figure 3. A primary winding 11 is wound by hand through the five elements 5-5 of the matrix transformer 10. Winding the primary winding 11 is a labor intensive manual operation. It is time consuming and requires considerable skill, yet the result is often messy. If the wires of the primary winding 11 cross in the matrix transformer 10, it can be difficult or impossible to get the required number of turns, and their arrangement is somewhat random yielding inconsistent product.
- [0005] Figure 5 shows a prior art printed circuit winding 15 for a matrix transformer, and figure 6 shows the printed circuit winding 15 installed in a matrix transformer 20. A plurality of terminal pins 21-21 connect the printed circuit winding to a mother board, both to complete the turns

around the end of the matrix transformer 20 and for connection to external circuitry. This arrangement has several problems. One is that the vias in the printed circuit winding occupy space that restricts the conductor area of conductors that must pass the vias. Another is the current crowding that occurs at the via. Also, usually a number of the turns of the primary winding just wrap around the transformer, not requiring any termination, yet every turn of the printed circuit winding 15 is connected through the mother board.

SUMMARY OF INVENTION

- [0006] This invention teaches that a laminated primary winding may be fabricated with stepped exposed surfaces of the several layers of the laminated primary winding, each having an arbitrarily large contact area for rugged, high current terminations. Windings that do not need to be terminated externally can be connected directly side to side. In some embodiments of the invention, the stepped exposed surfaces are on one end of the transformer. In other embodiments, the stepped exposed surfaces are mated to and soldered to complementary stepped exposed surfaces of a mating laminated winding within the transformer.

BRIEF DESCRIPTION OF DRAWINGS

- [0007] Figure 1 shows a prior art magnetic core.
- [0008] Figure 2 shows the core of figure 1 in phantom and shows two prior art secondary windings installed therein.
- [0009] Figure 3 shows a prior art matrix transformer "element".
- [0010] Figure 4 shows a prior art matrix transformer with a wound primary winding.
- [0011] Figure 5 shows a prior art printed circuit primary winding for a matrix transformer.
- [0012] Figure 6 shows a prior art matrix transformer with a prior art printed circuit primary winding.
- [0013] Figure 7 shows a laminated primary winding of this invention for a matrix transformer.
- [0014] Figure 8 shows the laminated primary winding of figure 7 installed in a matrix transformer.
- [0015] Figures 9, 10 and 11 show the terminations for the laminated primary winding of figures 7 and 8 in more detail.
- [0016] Figure 12 shows a laminated primary winding of this invention for a matrix transformer.
- [0017] Figure 13 shows the laminated primary winding of figure 12 installed in a matrix transformer.
- [0018] Figures 14 shows the terminations for the laminated primary winding of figures 12 and 13 in more detail.

- [0019] Figures 15 through 20 show alternative terminations for the laminated primary winding of figure 12. Figure 20 is a finished matrix transformer using the laminated primary winding of figure 12.
- [0020] Figure 21 shows one of a pair of mating laminated primary windings having stepped exposed complimentary mating contact areas. Figure 22 shows a pair of mated laminated primary windings, and figure 23 shows the mated laminated primary winding installed in a matrix transformer and terminated with pins.
- [0021] Figure 24 shows complementary stacks of metal foil windings (with the insulation not shown, for clarity) for use in a matrix transformer. Figure 25 shows the same complimentary stacks of metal foil windings placed together in their installed positions.
- [0022] Figure 26 shows that a winding similar to the winding of figures 24 and 25 can be molded into complementary assemblies.
- [0023] Figure 27 shows two molded laminated primary winding assemblies installed in a matrix transformer as a push pull primary winding.
- [0024] Figure 28 shows that the stampings of a laminated primary winding preferable have chamfered leading edges in

the direction of engagement, and that the solder may have therein small balls of copper, for spacing.

DETAILED DESCRIPTION

[0025] Figure 1 shows a prior art magnetic core 1 as may be used to make a matrix transformer. Note in particular that the magnetic core 1 does not have a gap, it is one solid piece. Because of that, the core is not assembled around a winding as in a conventional transformer. The winding has to be inserted through the center hole of the magnetic core 1. Figure 2 shows the magnetic core 1 of figure 1 as a phantom core 4, with prior art first and second secondary windings 2 and 3. Figure 3 shows a prior art "element" 5 of a matrix transformer comprising a pair of magnetic cores 1, 1 which are the magnetic core 1 of figure 1 each further comprising first and second secondary windings 2 and 3. The secondary windings 2 and 3 may be connected in various arrangements as required by a particular application. As examples, not limitations, they may be connected in series for higher voltage or as a "half turn" winding for lower voltage, higher current applications.

[0026] Figure 4 shows a prior art matrix transformer 10 comprising five magnetic elements 5-5 that are the magnetic element 5 of figure 3. Because the magnetic cores of the ele-

ments 5-5 are solid one piece cores, the winding must be inserted through the center holes of the elements 5-5. A primary winding 11 is wound by hand through the five elements 5-5 of the matrix transformer 10. Winding the primary winding 11 is a labor intensive manual operation. It is time consuming and requires considerable skill, yet the result is often messy. If the wires of the primary winding 11 cross inside of the matrix transformer 10, it can be difficult or impossible to get the required number of turns, and their arrangement is somewhat random yielding inconsistent product.

- [0027] Figure 5 shows a prior art printed circuit winding 15 for a matrix transformer, and figure 6 shows the printed circuit winding 15 installed in a matrix transformer 20. The printed circuit winding is made in a "U" shape, open at one end, with slender legs suitable for inserting through center holes in solid magnetic cores. To complete coils for a transformer primary winding, the windings in a printed circuit winding such as the printed circuit winding 15 must be completed by external connection from side to side at the open end after it is assembled into a matrix transformer. A plurality of terminal pins 21-21 may connect in vias 16-16 in the printed circuit winding 15 to a

mother board. This arrangement has several problems. One is that the vias 16-16 in the printed circuit winding 15 occupy space that restricts the conductor area of conductors that must pass the vias 16-16. Another is the current crowding that occurs at the vias 16-16 where they interface with the several layers within the printed circuit winding 15 . Also, usually a number of the turns of the primary winding just wrap around the transformer, not requiring any termination, yet every turn of the printed circuit winding 15 is connected through the mother board.

[0028] Figure 7 shows a laminated primary winding 20 for a matrix transformer having stepped terminations 22. The stepped terminations 22 are the extended ends of a plurality of "U" shaped sheet metal windings within the laminated primary winding 20, successively stepped so each of the sheet metal winding has a generous exposed electrical contact areas as terminations for making interconnections within the transformer and for making electrical connections to circuitry that is external to the matrix transformer. "U" shaped sheet insulation between the sheet metal winding layers keeps the winding layers separated and electrically isolated, and the insulation is preferably extended somewhat to ensure electrical separation.

ration and discourage bridging of solder. The insulation may be separate pieces, or it may be a film or coating on the sheet metal windings.

[0029] Figure 8 shows the laminated primary winding 20 installed in a matrix transformer 21. The stepped terminations 22 may be connected in a variety of ways for different applications. In figure 8 the laminated primary winding 20 is connected as a push pull winding as an example, not a limitation. Figures 10 and 11 show the push pull connection in more detail. A start termination 25 comprises a copper wire connection which extends downward sufficiently to be a through hole termination for a printed mother board. Similarly, an end termination 23 comprises a copper wire connection which extends downward sufficiently to be a through hole termination for a printed mother board. A center-tap connection 24 comprises a copper wire connection that connects the laminated winding 20 from one side of the laminated winding 20 to the other and then continues extending downward sufficiently to be a through hole termination for a printed mother board. A plurality of side to side jumper wires 26-26 connect those turns of the laminated primary winding 20 that do not connect to the external circuitry. The through hole

configuration is an example, not a limitation, as obviously they could be configured in many ways, wire leads, surface mount pads, screw terminals, slip fit terminals, and so forth as would be well known to one skilled in the art. Also, the center-tap termination 24 could alternatively be terminated with two separate wires so as to make a split winding primary, or the center-tap could be simple another side to side jumper 26 to make a single coil primary winding.

- [0030] Figure 9 shows the stepped terminations 22 of the laminated primary winding 20 of the transformer 21 in more detail. It can be seen that a plurality of copper foil windings 31-31 are separated by layers of insulation 32-32. Although not shown, the outside surface of the laminated primary winding 20 is preferably coated or wrapped with insulation before inserting it into the elements 5-5 of the transformer 21.
- [0031] Note in figure 9 that each layer of insulation 32-32 extends slightly beyond the copper foil windings 31-31 so as to define a termination area that has sufficient exposed copper surface to make a rugged connection yet is separated from layer to layer to prevent solder bridging or short circuits. Although solder connections are recited,

that is as an example, not a limitation, as it would be possible to fashion a mechanical connector with contacts to perform a similar termination function or to connect and interconnect the stepped terminations 22 in a variety of ways, as would be well known to one skilled in the art of electrical assembly.

- [0032] The laminated primary winding 20 could be made using usual printed wiring board techniques by etching the "U" shaped windings, stacking and bonding multiple layers, then cutting away the excess material as by routing. Alternatively, "U" shaped stampings could be stacked with pre-preg "U" shaped insulation to make a finished assembly in one pressing and molding operation. However, a preferred alternative method of making the laminated winding 20 is to assemble large strips of copper into long laminated assemblies of copper stacked with insulation with the edges extended in steps to become the future termination areas. This can be a continuous process using rolls of copper stock and insulation stock. After lamination and curing of the adhesives, the bars can be cut into short sections and can be machined into "U" shapes. The cutting and machining will likely smear the edges, causing layer to layer short circuits, but these short circuits can be

removed easily with a simple etching process to etch back the copper so as to be flush or slightly below flush with respect to the insulation on the sides of the laminated windings. A dip coat or wrap of insulation then completes the assembly. The exposed copper termination areas may be tin plated, and this is preferred if the laminated winding may be stored for a period of time. However this would not be necessary if they were fluxed and soldered soon after fabrication.

- [0033] Figure 12 shows a laminated primary winding 40 in which the laminated layers are oriented vertically (in contrast to the horizontal orientation of the laminated primary winding 20 of figure 7). It is similar to the laminated winding 20 of figure 7 in having stepped terminations 41. To distinguish the laminated primary winding 20 of figure 7 from the laminated primary winding 40 of figure 12, the laminated primary winding 20 of figure 7 has "flat stacked "U" shaped windings" whereas the laminated primary winding 40 of figure 12 has "nested "U" shaped windings".
- [0034] The laminated primary winding 40 of figure 12 may be fabricated of copper strip of uniform width (the height of the laminated primary winding 40), formed in successive "U" shapes, nested and bonded with interleaved insulating

layers. The result may have a stepped termination 41 which is similar in design to the stepped termination 22 of figure 9 except for its vertical orientation. However, a preferred alternative method of fabrication would have long sheets of copper folded into nesting "U" shaped sheets with interleaved insulation sheets bonded together into long "U" shaped assemblies, perhaps as a continuous process using rolled stock. The strips can then be cut across to make the laminated primary windings 40 with no waste except the saw cut. Likely the cutting process would cause some copper smearing from layer to layer, and any resulting short circuits can be removed by back etching. A final dip or wrap of insulation would insulate the edges, Figure 13 shows the laminated primary winding 40 installed in a matrix transformer 46 comprising five elements 5-5, as an illustration, not a limitation. The stepped termination areas 41 are wired with "U" shaped wires to connect and terminate the primary windings, as shown in more detail in figure 14. A "U" shaped start winding 42 is in the center. Although it is "U" shaped, and touches both ends of the laminated primary winding, it connects only to one side as indicated comprising the start of the winding. On the other side, it may contact an area of the stepped ter-

mination area 41 that is insulated, or it may have an insulating coating or sleeve. Regardless, it can be put in place and will be self-fixturing until it is soldered. Similarly, a "U" shaped end winding 44 bridges both ends of the laminated primary winding 40, but it connects with just one side as indicated comprising an end connection.

- [0035] A center-tap termination 43 is also "U" shaped, but contacts termination areas on both sides of the laminated primary winding to make both a side to side connection and also a connection for connecting the matrix transformer 46 to a mother board or other circuitry. A plurality of "U" shaped jumpers connect the other windings from side to side as necessary to complete the transformer coils. The connections shown in figures 13 and 14 are for a push pull primary winding, as an illustration, not a limitation. Other winding arrangements such as split coils or a single coil can be easily accommodated by modifying the interconnections and terminations, as would be well understood by one skilled in the art of transformers.
- [0036] Figures 15 through 20 show a matrix transformer 50 using the same laminated primary winding 40 but having much more substantial stamped metal terminations and interconnections. Figures 16, 17 (a section view) and 20

show the completed matrix transformer 50, while the other figures show partly assembled terminations, for clarity. A push pull primary winding connection is shown as an illustration, not a limitation.

- [0037] Figure 15 shows that a start termination 52 and an end termination 54 is installed. The start winding 52 bridges between the sides of the laminated primary winding 40, but as with the start termination 42 of figures 13 and 14, it is connected on just one side, as indicated, and is insulated on the other. Because it is wedged between the ends of the laminated primary winding, it is self-fixturing until it is soldered. With reference to the section view shown in figure 17, the right side of the start winding 52 is connected as indicated, and the left side is insulated from the conductors of the winding 40.
- [0038] Similarly, the end termination 54 comprises a stamping that frames the winding 40. The end termination 54 is connected on just the end side as indicated (the A side in figure 17), and is insulated from the laminated primary winding 40 o the other side (the .A' side) However, by using a structure that surrounds the whole structure, it is self-fixturing until it is soldered.
- [0039] Next a plurality of side to side connections 55 and 56 are

installed. Additional external side to side connections 55 and internal side to side connections 56 are used to complete the winding connections that do not connect to external circuitry. Lastly, an internal side to side connection comprising a center-tap termination 53 is installed. The start 52, the end 54 and the center-tap 53 are shown with surface mount feet as an example not a limitation. It is contemplated that the windings may be assembled with solder paste in place and that the whole maybe be reflowed after assembly. However it could be soldered manually with each operation. The connection and termination stampings could also connect by friction, or they could be assembled into a connector like assembly that slips onto the stepped ends 41 of the laminated winding 40.

- [0040] Figures 21 through 23 show a matrix transformer 80 having five elements 5-5 (as an illustration, not a limitation) and a laminated primary winding 70. The laminated primary winding 70 comprises mating first and second laminated sub-assemblies 61 and 69 having complementary stepped connection areas.
- [0041] Figure 21 shows the first laminated sub-assembly 61. It comprises six "U" shaped copper stampings 61 through 66 stacked with stepped exposed surface termination ar-

eas, and with insulation 67-67 between the layers and on the outside surfaces. Figure 22 shows that a similar second laminated sub-assembly 69 may be mated with and soldered to the first laminated sub-assembly 61 to comprise the laminated primary winding 70. Vias 68-68 may connect the several layers of the laminated primary winding 70 and, as shown in figure 23, may receive terminating pins 71-71 for connection to external circuitry. As contrasted with the vias 16-16 of figure 5, the vias 68-68 are beyond the main winding area of the laminated primary winding 70 so they do not crowd the conduction path. Further, only those vias that connect to external circuitry need to have terminating pins 71-71.

- [0042] As an alternative to the vias 68-68, the various layers of the laminated primary winding 70 could have tabs extending from the layers that are to be connected externally.
- [0043] It is contemplated that the stepped termination areas of the first and second laminated sub-assemblies 61 and 69 would be tinned generously or coated with solder paste, then they would be assembled into the matrix transformer 80 with a clamping means (not shown) urging them into close contact. The clamping means could be a springy

member or some elastic material, or it could be clamping fingers reaching between the elements 5–5 to clamp them together. Regardless of how they are held together, it is contemplated that the matrix transformer 80 would be heated to cause the solder to reflow.

[0044] Figures 24 and 25 show in more detail how complementary stacks of metal stampings 103 through 115 maybe arranged to make a laminated primary winding 100 comprising first and second laminated sub-assemblies 101 and 102. Figures 24 and 25 are shown in exaggerated scale, spread apart and without the insulation so that the resulting winding can be traced to better understand the interconnections. Note that the stamped windings 103 and 115 are extended so as to provide self-terminations for the laminated primary winding 100.

[0045] Figure 26 shows a laminated primary winding 120 comprising first and second laminated sub-assemblies 121 and 122. The internal construction and interconnection maybe as shown in figures 24 and 25, and extensions of two or more of the internal layers may comprise self-terminations 123 and 124. Insulating sleeves 125, 125 may be used over the laminated primary winding 120 to provide greater dielectric isolation. It is to be understood

that the laminated primary winding 120 and its insulating sleeve would not be assembled outside of a matrix transformer, and figure 26 shows them assembled only to illustrate certain details that are hidden in the final assembly. The insulating sleeves 125–125 should fit closely to the laminated primary winding, and it may have shrink sleeve properties which could be useful in urging the first and second laminated sub-assemblies 121 and 122 together for reflow soldering. For illustration only, not as a limitation, the insulating sleeves are shown as being transparent so that the stepped connection between the first and second laminated sub-assemblies 121 and 122 can be seen.

- [0046] Figure 27 shows a matrix transformer 130 having five elements 5–5 (as an illustration, not a limitation) and two laminated primary windings 131 and 132. The laminated primary windings 131 and 132 have self terminations 133–133, and could be connected either as a push pull winding, in series, in parallel or as a split winding. It is contemplated that each of the laminated primary windings may be similar to the winding 120 of figure 26. It is also contemplated that an expansion means (not shown) may be used between the laminated primary windings 131 and

132 to urge them apart and to provide a clamping force when they are assembled and reflow soldered. Also, by urging them apart and into good contact with the secondary windings of the matrix transformer 130, heat sinking is improved. The expansion means might be a springy or elastic member inserted between the laminated primary windings 131 and 132.

[0047] Figures 21 through 27 show subassemblies made of flat stacked "U" shaped windings, but equivalent subassemblies can be made with nested "U" shaped windings, and their function would be the same.

[0048] Figure 28 shows a section through a small portion of the complementary stepped contacts of a laminated primary winding 150 of this invention. A first laminated sub-assembly 151 may comprise metal stampings 153 and 154 separated by an insulator 155. A second laminated sub-assembly 152 may comprise metal stampings 156 and 157 separated by an insulator 158. Note that the metal stampings 153 to 157 have chamfered leading edges in the direction of engagement, to ensure that they can slide past each other when inserted into the matrix transformer elements and possible insulating sleeve without hanging up even if it is a tight fit.

- [0049] The first and second laminated sub-assemblies 151 and 152 may be mated and reflow soldered under a clamping pressure. A problem with soldering flat surfaces under a clamping pressure is that the clamping pressure tends to squeeze the solder out of the joint which may compromise the joint and which may also cause other problems as excess solder flows where it should not. It is not the best solution simply to use much less solder, as it may be insufficient to make a good joint.
- [0050] In figure 28, the solder 160-160 in the joints contains a plurality of small balls 161-161, preferably of a material such as copper that is conductive and easily wetted by the solder 160-160. These small balls 161-161 space the metal stampings 153, 154, 156 and 157 apart so that the solder 160-160 cannot be squeezed out, and so that the volume of the contact is known and fixed as the area of the contact times the diameter of the small balls. Accordingly, a metered portion of solder can be used, and it will be known to be just the correct volume.
- [0051] Because transformers are reciprocal devices, a recitation in the specification or the claims of "primary" or "secondary" are for convenience, and they include transformers which may be connected differently or in reverse.

[0052] The teachings of this invention can be used with a single core transformer, and would be particularly useful for making a transformer with a gap-less magnetic core for reduced reluctance in the magnetic circuit. Accordingly, although a matrix transformer usually has a plurality of elements, when a "matrix transformer" is recited in this specification and the claims, it includes a transformer having a single element or core.

[0053] A "sheet metal winding" is a winding fabricated of flat stock or thin bar stock, preferably copper, suitable for stacking or nesting to make a laminated primary winding. It may be fabricated by cutting from a coil, forming, stamping, etching, plating or other means. A "sheet insulation" is a thin layer of insulating material for electrically isolating one layer of a laminated primary winding from the other layers. It may comprise an insulator cut from a coil, stamped from a sheet, die cut, molded, extruded, pressed or other means, and it may be an insulating film or coating that is applied by painting, spraying, dipping, vacuum deposition, wrapping or other means. It may have a free shape, or it may acquire a shape, for example a "U" shape, by virtue of being a coating or film on a sheet metal winding having the recited shape.